Research Article

Shear bond strength after various recycling processes of rebonded damon brackets: a comparative in vitro study.

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Abstract: Background: This study aims to investigate the effect of various recycling techniques on metal self-ligating Damon brackets' shear bond strength. Materials and methods: Fifty-four Damon Q self-ligating brackets in total were split into two different groups: the first group, which included the control group, had 18 new brackets, and the second group, which included 36 new brackets that were bonded to typodont and then debonded using a tweezer. Eighteen debonded brackets were split into two experimental groups for recycling (sandblasting and tungsten carbide bur). The fifty-four removed upper first premolar teeth were then fitted with all of the brackets using a uniform bonding technique. Every specimen's shear bond strength was assessed using a universal testing machine until the bond breakup. The data were statistically analyzed using the ANOVA F-test in SPSS version 26. $P \leq 0.05$ was considered significant for all statistical tests. Result: Using the ANOVA F-test, it was found that there were significant differences in the mean value of the shear bond strength for each group. Moreover, the mean value of shear bond strength for the new bracket group had the highest value (5.99± 0.40 MPa), followed by the sandblasting group (5.94 ± 0.11 MPa), and the tungsten carbide bur group had the lowest value (4.27± 0.75 MPa). Conclusion: For repositioning of rebounded Damon brackets, shear bond strength that is clinically acceptable would be produced by the sandblasting procedure, while the tungsten carbide bur method would result in lower shear bonding strength and bracket base mesh loss.

Keywords: Damon, Recycling, Sandblasting, tungsten carbide bur, Self-ligated brackets, SEM

Introduction

In terms of performance, self-ligating brackets claim to be better than traditional brackets in reducing friction and treatment time [(1)], less subjective discomfort [(2)], lower bacterial count on bracket surface, and improved periodontal health due to poor bio-host ability; however, there is no difference in arch dimensions [(3,4)], and more expensive than conventional brackets [(5)].

At the end of the course of treatment, the attachments need to be simple to remove and cause the least amount of damage to both soft and hard tissues when applied [(6)]. During orthodontic treatment, orthodontic bracket bonding frequently fails; reports of this phenomenon range from 3.5% to 23% [(7)]. Debonding of orthodontic attachments during therapy is not unusual. Two primary reasons for this are poor bonding and biting forces [(8)]. Bracket repositioning may also be necessary due to incorrect bracket placement specifically; in Damon's philosophy, a bracket panoramic-repositioning is a requisite step conducted to evaluate crown-root alignment before working phase commencement. Therefore; debonding during treatment lengthens the treatment time and cost [9]. Knowing that Damon brackets are already expensive; for this reason, recycling orthodontic brackets is an important procedure. Like orthodontic retainers, many researches were carried out to study recycling methods [10]. Many methods, such as using various tungsten carbide burs, sandblasting, and different types of lasers, have been proposed for clearing resin residues from the bracket base or enamel surface and preparing the surfaces following debonding [11]. There are several disadvantages of reusing orthodontic brackets, including the possibility of bracket distortion [12], time-consuming and lower shear bond strength (SBS) with the direct flame method [13]. On the other hand, the use of new Damon brackets at the pano-repo step is squandering and has a cost-benefit issue. The design of the bracket base, the amount of adhesive residue left on it, the manner used to remove the bracket, and microscopic base damage all have an impact on the SBS of recycled brackets [14] while the oral environment doesn't affect it [15]. Bahnasi et al [16] concluded that recycling brackets with 50-μm aluminium oxide powder did not degrade the stainless steel brackets' SBS and that it could be a cost-effective substitute for new brackets. Additionally, he came to the conclusion that decreased SBS was demonstrated by bracket recycling using grinding, heating, or chemical processes.

This research aimed to evaluate the impact of sandblasting and tungsten carbide bur on the surface roughness of debonded metal brackets of the Damon Q system as well as the post-recycling morphological alterations of the bracket bases.

Materials and Methods

This in vitro study was approved by the ethics committee of Baghdad University, College of Dentistry (Approval Number: 764423, Date: 12 Jan 2023). The research was carried out between March 2023 and September 2023. The sample size was calculated using the G*Power 3.1.9.6 algorithm (Franz Faul, Unikiel, Germany). The effect size was 0.55 and it was calculated according to the standard deviation of the previous study by Bahnasi et al. [17], 2013 (SD of groups were 8.77, 5.45, 9.15) and the sample size was 180 extracted human premolar teeth divided into 5 groups, the level of significance is 0.05, the power of a study is 0.95, the sample size was 54 recently removed upper first premolar teeth from Iraqi patients (15-25 years) seeking orthodontic treatment in Orthodontic department in the College of Dentistry/Baghdad University and some private clinics at Karbala city [18]. Following extraction, the teeth were cleaned and rinsed with water to get rid of any remaining soft tissue, blood, and debris according to CDC's Guidelines for Infection Control in Dental HealthCare Settings (2003). They were then placed in a 0.1% (weight/volume) thymol solution for storage. The entire buccal surfaces of the teeth inspected visually after driness, and it represent absence of cavities, absence of fractures, and absence of a hypoplastic region which is the inclusion criteria for tooth selection. The teeth were separated into three groups; each group contained eighteen teeth. The control group (group C) contained new eighteen brackets, while the remnant of the brackets was divided into two groups recycled by sandblasting (group SB) and tungsten carbide bur (group TB). Before bonding, the teeth were inserted into cold-cure acrylic blocks, which were coded for randomization [19]. Using a randomization plan generator (randomization.com)[20], The sample size and number of groups were entered and the website distributed the samples using simple randomization into three equal groups.

Brackets and Grouping

In this investigation, fifty-four passive self-ligating upper first premolar Damon Q™ brackets (Ormco Company, California, USA) were utilized. The brackets' base had mechanical interlocking pads, with a slot size of 0.022 x 0.028 inches. The brackets' base area was 8.6mm^2. The brackets were split into two groups: eighteen brackets were randomly selected for the C group, and the remaining thirty-six brackets were randomly selected and equally split into two experimental groups (group SB, TB), with eighteen brackets per group.

Sample Preparation and Recycling Procedure

First, a total of thirty-six orthodontic brackets were bonded with Transbond XT (3M Unitek Transbond™ XT Light Cure Composite, USA) [(21)] to tooth surfaces of typodont that are not etched and wet slightly. After that, excess bonding material was removed with a probe, light-cure was used for 20 seconds on the brackets, and debonding orthodontic brackets from typodont were made according to Chung et al. [(22)]. Debonding of brackets was carried out with a tweezer. After that, debonded brackets were divided into two groups according to the method used for recycling:

Group C: Contain new brackets that acted as a control group.

Group SB*:* A micro-etcher air abrasion master (NSK® PTL coupling type, M&Y) was used to remove the adhesive. Sandblasting was done at 65 psi for 20 to 30 seconds using 50 μm aluminium oxide abrasive powder, keeping a 5 mm space between the bracket's base and the handpiece head. After the adhesive was completely invisible to the naked eye, each sandblasting bracket was cleaned using an air spray for 5-7 seconds[(23)].

Group TB*:* To remove the adhesive, a high-speed handpiece containing tungsten carbide burs (OS International Orthodontics Services, Capricorn St., Stafford, TX, USA), was used until the adhesive was not visible to the naked eye, and then each bracket was cleaned with an air spray for 5-7 seconds [(17)].

Rebonding Procedure

A total of fifty-four extracted premolars were used. The enamel surfaces were cleaned for five seconds using a low-speed handpiece and a nylon brush that was free of fluoride. This was followed by ten seconds of water rinsing. Every tooth's central crown section was etched for 30 seconds using 37% phosphoric acid, and then the area was washed with water for another 30 seconds. After that, the samples were slowly dried with air for ten seconds, causing the enamel to take on a white, chalky appearance. The etched enamel surface was first coated with a thin layer of bonding agent. Next, a tiny quantity of light curing composite (3M Unitek Transbond ™ XT Light Cure Composite, USA) resin was added to the bracket's base, and the bracket was positioned in the middle of the dental surface. A dental explorer was used to provide point pressure to the middle of the bracket, remove any excess composite resin, and then apply light-cure (Woodpecker, I-plus, Hong Kong, China) to the brackets for 20 seconds. The samples were kept at 37ºC in distilled water. After 24 hours the samples undergo SBS testing by Universal testing machine.

Shear Bond Strength Test

Tinius-Olsen A universal testing machine (H50KT, England) with a load cell of a 5 KN with a crosshead speed of 0.5 mm/minute was used to perform a shear test at the University of Technology's Metallurgical Engineering Department in Baghdad, Iraq. The machine have mechanical calibration to measure shear bond strength and the calibration is carried out according to international standards ISO 29022. The specimen was fixed in the testing machine's lower jaw, and a specially made chisel rod was used to apply a load from the occlusal to the gingival direction at the interface between the bracket and tooth. Up until the bond failed, the debonding pressures were noted [(24)]:

Shear bond strength value (MPa) = force (N) / bracket surface area (8.6 mm^2).

The SBS of the C group was considered a baseline, according to which the bond strengths of the recycled brackets were measured.

Scanning Electron Microscopy Examination

The SEM observations were conducted on one bracket from each of the three groups, using magnifications of x500 and x1000 [13].

Atomic force microscopy (AFM)

Surface roughness and particle sizes of materials were analyzed using atomic force microscopy (CoreAFM 2023 model, manufactured by Nanosurf AG in Switzerland). The scan area used for measurements was 15µm x 15µm and the analysis was conducted at the general service lab in the Chemistry department, College of Sciences at the University of Baghdad.

The sample was placed on a sample holder mounted on a magnetic disk, and the measurements were taken using an AFM probe in tapping mode. The probe had a gold reflecting coating on the tip side of the cantilever (Tap190GD-G) and the detector side was coated with 70 nm of gold. The cantilever's force constant ranged from 28 to 75 N/m and the probe specifications included a beam shape with a cantilever length of 225 µm, a width of 38 µm, and a resonance frequency of 190 kHz.

Statistical Methods

SPSS software 26 (Chicago, USA) was used for all statistical analyses. Shapiro–Wilk test was performed to evaluate data distribution. Descriptive statistics including mean, standard deviation, minimum, and maximum were analyzed for the C, SB, and TB groups. One-way ANOVA and Tukey's tests were employed to compare the mean of SBS and Ra among the three groups. For every statistical test, at the 0.05 level, the mean difference is statistically significant.

Results

A normality test was done to check the data distribution, the Shapiro-Wilk test showed that data of all variables was normally distributed. The SBS descriptive data for each group was displayed in Table 1 and Figure 1. The SBS for each group was displayed in Table 2 with an ANOVA, and a significant difference ($P < 0.05$) was found between the studied groups.

Table 1: shows the SBS (MPa) descriptive data for the various groups.

	Mean	SD	SE	Minimum	Maximum
C	5.99	0.40	0.73	5.31	6.34
SB	5.94	0.11	0.04	5.81	5.98
TB	4.27	0.75	0.192	3.15	4.57

C: control; SB: Sandblasting; TB: Tungsten carbide bur

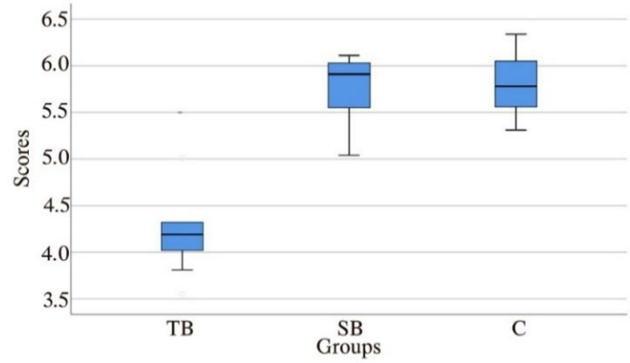

Figure 1. Boxplot representation of shear bond strength (SBS) values for the three experimental groups: Control (C), Sandblasting (SB), and Tungsten Carbide Bur (TB). Y-axis (Scores) represent Shear Bond Strength in MPa, X-axis (Groups) represent the three groups (C, SB, TB). The boxes indicate the interquartile range.

Table 2: One-way ANOVA for comparison of SBS between groups.

ANOVA	Sum of Squares	df	Mean Square	F	*P-value*
Between Groups	33.61	2	16.80	62.44	0.001
Within Groups	13.46	51	0.27		
Total	47.07	53			

The three groups' differences can be seen in the SEM photographs. Typical SEM pictures of bracket bases are shown in Figure 2. Typical SEM pictures of bracket bases (the new bracket for the C group) are shown in Figure 2a, while the images of the brackets after they had been sandblasted revealed adhesive residue and a noticeable micro-roughening of the bracket bases (Figure 2b). However, photographs of TB brackets revealed flattening and loss of meshwork, in addition to an incomplete removal of adhesive from the bracket's base (Figure 4c).

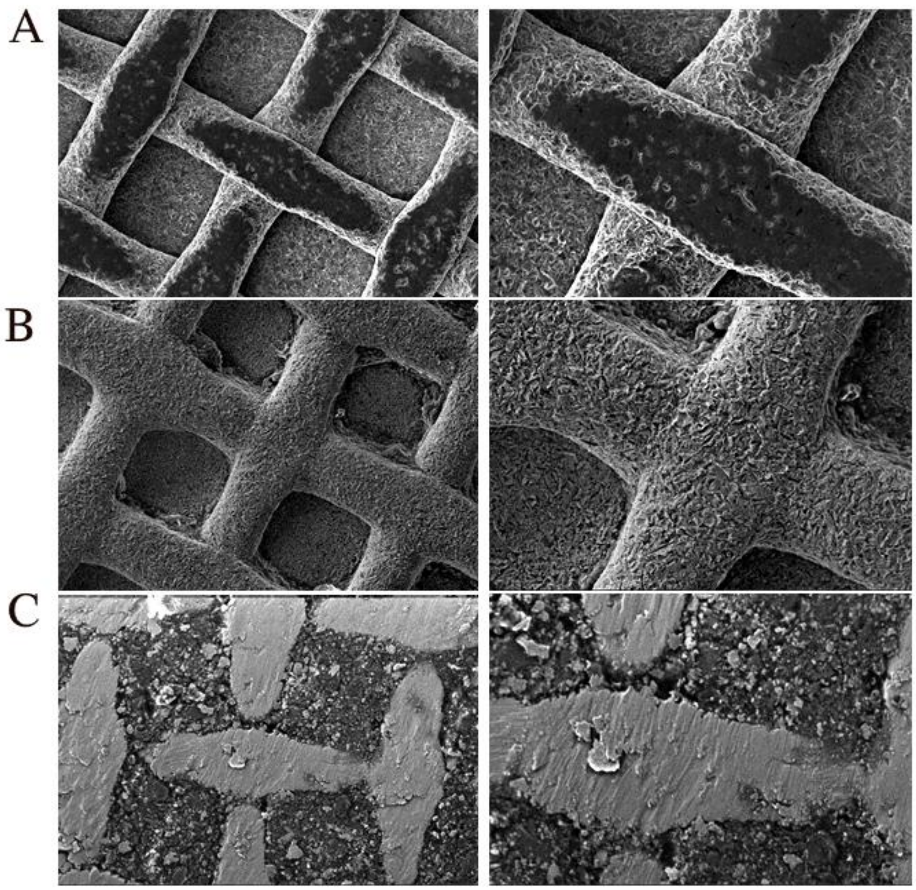

Figure 2: Typical SEM pictures of bracket bases: (a) group C: Control bracket (b) group SB*:* Sandblasting bracket and (c) group TB*:* Tungsten carbide bur bracket (under x500; and under x1000 magnification).

AFM and surface roughness assessment was carried out in the current *in vitro* study. The topographies of the height parameter display the surface roughness profile shown in Figure 3 of (a) group C: Control bracket, (b) group SB: Sandblasting bracket and (c) group TB: Tungsten carbide bur bracket. As the standard deviation of all the height values (Table 3), the average roughness parameter values (Ra) are calculated as 58.715 nm, 55.88 nm, and 94.39 nm for C, SB and TB groups respectively, which describes the overall surface roughness. The root mean square roughness (Rq) parameter is 75.185nm, 69.39nm, and 121.35nm respectively, indicating the height distribution relative to the mean line. The parameter Rz indicates the average maximum peak-to-valley height or maximum roughness values are coherent with Ra values, which indicates that SB has low roughness compared to all groups.

Table 3: Sample group of the average roughness (Ra), root mean square roughness (Rq) and average maximum roughness (Rz)

Groups	Ra (nm)	Rq (nm)	Rz (nm)	Rsk
C	58.715	75.185	494.15	0.5752
SB	55.88	69.39	426.31	0.3924
TB	94.39	121.35	803.55	0.7276

C: control; **SB**: Sandblasting; **TB**: Tungsten carbide bur

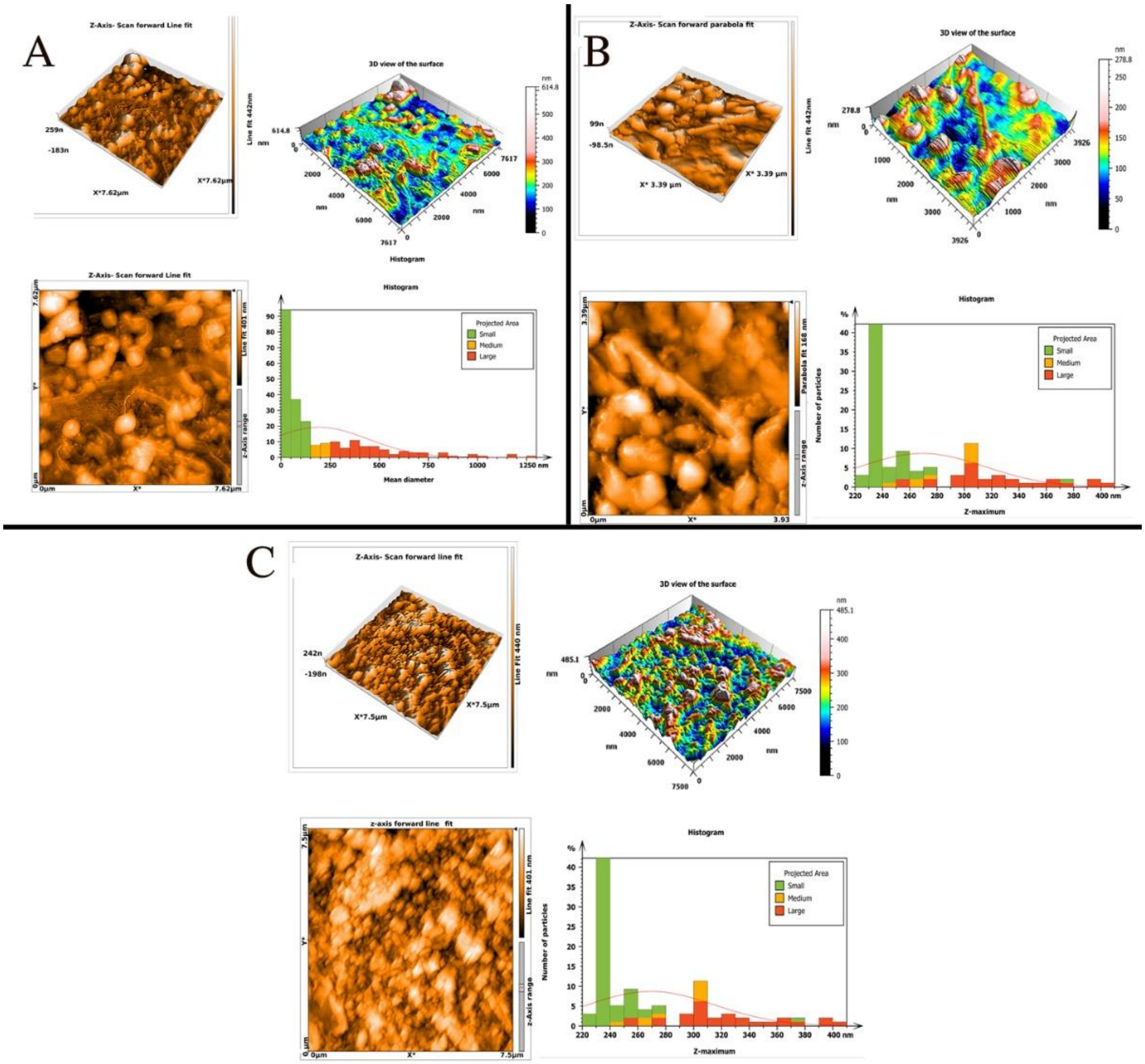

Figure 3. AFM images of the measures surface: (a) group C: Control bracket (b) group SB*:* Sandblasting bracket and (c) group TB*:* Tungsten carbide bur bracket.

Discussion

Orthodontic research has shown a considerable deal of interest in the shear bond strength of both new and recycled brackets [25]. With the use of tungsten carbide bur and sandblasting, the SBS of recycled self-ligated brackets was to be evaluated and compared with that of new brackets in this study. In this study, the C group had the greatest mean SBS value (5.99± 0.40 MPa), followed by the SB group (5.94 ± 0.11MPa), whereas the TB group had the lowest mean SBS value (4.27± 0.75MPa). Post hoc Tukey's HSD test showed significant differences between the TB group, the SB group, and the C group, but not between the C and SB groups. The mean SBS of the SB and C groups was within the range that Reynolds and Von Fraunhofer [26] suggested (For brackets attached to teeth to overcome intraoral and orthodontic stresses, SBS in the range of 5.8 to 7.8 MPa was necessary). This was consistent with what Sonis had stated in his study. He stated that, if the bracket slot has not been distorted, sandblasting seems to provide a practical way for clinicians to repurpose recently unsuccessful bonded brackets [27].

Sandblasting is frequently used in orthodontics to remove adhesives from the base of brackets, roughen composites, and etch enamel. In addition to altering the entire base surface and eliminating the majority of the delicate undercuts on the bonding pads of the brackets, sandblasting removes some of the adhesives from the base of the bracket and fills some of the tiny holes that act as a retentive mean for the brackets [14].

Research by Kachoei et al [28] found no evidence of statistically significant variations in bracket bond strength values during sandblasting recycling. The findings of this investigation aligned with those of Yassaei et al [14], who assessed the effectiveness of eliminating composite resin from bracket bases by using the sandblasting method.

In comparison to new brackets, the SBS of rebonded brackets treated with high-speed carbide bur was reduced and there is statistical significance difference between the SBS values of the two groups. This is consistent with the findings of Basudan and Al-Emran [29] who prepared the base of the bracket using green stone and found a markedly lower SBS than with brand-new brackets. According to Chacko et al. [30], the adhesive grinding process is not an acceptable way for recycling since the flattening and loss of meshwork, along with inadequate adhesive removal, caused the SBS value to be significantly below the value recommended for clinical usage.

Surface roughness refers to the texture of a surface and is quantified by the vertical deviations of the surface from its ideal form. it affects the mechanical properties, aesthetics, and usability of the parts (brackets). In orthodontic treatment, we used SEM and AFM to detect the roughness qualitatively and quantitatively.

The SEM showed that the newly constructed bracket bases had a smooth residual surface and a clearly defined, three-dimensional, mechanically retentive pattern with a few tiny hollows that serve as the brackets' retentive mechanisms. The sandblasting bracket base revealed that the mechanical retention was almost completely lost and the overall retentive pattern (undercuts) was distorted. The adhesive remnant appeared with roughness. The small holes appeared to be less deep, possibly because aluminium oxide particles were filling these holes. The tungsten carbide bur bracket group showed flattening and loss of base meshwork.

Regarding AFM, there was a significant difference in surface roughness between groups. In terms of roughness and shear bond strength, there was no significant difference between the C group and the SB group. The TB have the roughest surface resulting from the rotational movement of bur. These results are consistent with Hasan and Abood [31] who found that the surface roughness between new brackets and sandblasting brackets is nearly the same.

The findings of SBS showed that an increase in surface roughness wasn't correlated with an increase in bond strength. SB group have the second higher SBS; However, the AFM image showed a smoother surface. The reason is that the surface roughness and shear bond strength didn't correlate linearly [32]. The particle's diameter may have affected the surface roughness. In this study, the particles used have 50 µm which is the smaller diameter. Uo et al. [33] concluded that bonding strength was unaffected by variations in surface roughness. Increased roughness in the TB group is almost due to incomplete removal of adhesive.

Clinicians should consider the time and cost of cleaning and preparing bracket bases for rebonding, as well as the cost of additional supplies or tools. The in vitro environment remains different from the complex intra-oral situation, and, hence, the results should further be verified in clinical trials. Using other self-ligated bracket designs, such as esthetic self-ligated brackets in further research.

Conclusion

The SBS results of the current in vitro study revealed that Damon self-ligating metal orthodontic brackets recycled by sandblasting method would result in clinically acceptable SBS, while the tungsten carbide bur method would result in lower SBS than recommended.

Conflict of Interest

The authors have no conflicts of interest to declare.

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Informed consent

Informed consent was obtained from all individuals or their guardians included in this study.

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تأثير الطرق المستخدمة لازالة مادة التقويم اللاصقة من سطح حواصر الديمون المعدنية المنزوعة,دراسة محتبرية

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المستخلص:

الخلفية: تهدف هذه الدراسة الى معرفة تأثير طرق إعادة التكوين المختلفة على قوة الالتصاق القصوى والتغيرات المورفولوجية للحاصرات الذاتية الربط بعد إزالته. المواد والطرق: تم تقسيم اربعة وخمسون حاصرة ذاتية الربط من نوع Damon Q إلى مجموعتين؛ المجموعة الأولى تحتوي على 18 حاصرة جديدة (المجموعة التحكمية)، في حين أن المجموعة الثانية تحتوي على 36 حاصرة جديدة تم تثبيتها على نموذج تايبودنت مبلل قليلاً ثم تم إزالتها بواسطة ملقط. تم تقسيم الحاصرات المزيلة إلى مجموعتين تجريبيتين (معاد تكوينها) بواقع 18 في كل مجموعة, تم تثبيت الحاصرات الكلية على 54 سناً من الأضراس البشرية المقلوعة لاغراض تقويمية وفقًا لإجراء التثبيت الموحد. تم تخزين الأسنان في ماء مقطر عند 37 درجة مئوية لمدة 24 ساعة. بعد ذلك,تم تحديد قوة الالتصاق القصوى لجميع العينات باستخدام آلة اختبار عالمية حتى حدوث فشل الالتصاق. تم إجراء فحوص المظهر المورفولوجي لقواعد حاصرات Damon باستخدام المجهر الإلكتروني الماسح. تم إجراء التحليل الإحصائي باستخدام برنامج SPSS الإصدار 26 باستخدام اختبار-F ANOVA.

النتيجة: كانت هناك فروق كبيرة في متوسط قيم قوة الالتصاق القصوى بين جميع المجموعات باستخدام اختبار F-ANOVA ؛ علاوة على ذلك، كانت متوسط قوة الالتصاق القصوى للحاصرات الجديدة أعلى قيمة متوسطة، ثم المجموعة المفجرة بالرمل، بينما كانت لدى مجموعة مشقق كربيد التنغستن أدنى قيمة متوسطة لقوة الالتصاق القصوى. أظهرت صور SEM لقواعد الحاصرات التي تم معالجتها بالتفجير بالرمل أنه لم يتم إزالة كل اللاصق من قاعدة الحاصرة. الاستنتاج: تظهر أن طريقة الرملة النافثة ستؤدي إلى قوة الالتصاق القصوى المقبولة سريرياً لإعادة توضيب حاصرات Damon المرتدة، في حين أن طريقة مشقق كربيد التنغستن ستؤدي إلى قوة الالتصاق القصوى الأقل وفقدان لشبكة الحاصرة.